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PATENT APPLICATION  
TRANSMITTAL**

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

Attorney Docket No. 28870

First Inventor or Application Identifier Lambert Haner

Title CONTROLLED RELUCTANCE AC INDUCTION MOTOR

Express Mail Label No. EL355023653US

**APPLICATION ELEMENTS**

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Assistant Commissioner for Patents  
Box Patent Application  
Washington, DC 20231

1. ☒ \* Fee Transmittal Form (e.g., PTO/SB/17)  
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 25]  
(preferred arrangement set forth below)  
- Descriptive title of the invention  
- Cross References to Related Applications  
- Statement Regarding Fed sponsored R & D  
- Reference to Microfiche Appendix  
- Background of the invention  
- Brief Summary of the invention  
- Brief Description of the Drawings (if filed)  
- Detailed Description  
- Claim(s)  
- Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 9]
4. Oath or Declaration [Total Pages 1]  
a. ☒ Newly executed (original or copy)  
b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))  
(for continuation/divisional with Box 16 completed)  
i. ☐ DELETION OF INVENTOR(S)  
Signed statement attached deleting  
inventor(s) named in the prior application,  
see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b).

5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission  
(if applicable, all necessary)  
a. ☐ Computer Readable Copy  
b. ☐ Paper Copy (identical to computer copy)  
c. ☐ Statement verifying identity of above copies

**ACCOMPANYING APPLICATION PARTS**

7. ☐ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement of Power of Attorney  
(when there is an assignee)
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449 [Copies of IDS Citations]
11. ☐ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503)  
(Should be specifically itemized)
13. ☒ \* Small Entity Statement filed in prior application, Status still proper and desired  
(PTO/SB/09-12)
14. ☐ Certified Copy of Priority Document(s)  
(if foreign priority is claimed)
15. ☒ Other: Check in the amount of \$ 423.00

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16. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment:

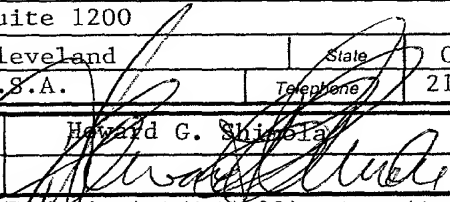
☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: \_\_\_\_\_

Prior application information: Examiner \_\_\_\_\_ Group / Art Unit: \_\_\_\_\_

For CONTINUATION or DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 4b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

**17. CORRESPONDENCE ADDRESS**☒ Customer Number or Bar Code Label 000,116 or ☐ Correspondence address below  
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Signature		Date	Sept. 6, 2000

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See 37 C.F.R. §§ 1.27 and 1.28.

TOTAL AMOUNT OF PAYMENT (\$ ) 423.00

## Complete if Known

Application Number  
Filing Date  
First Named Inventor Lambert Haner  
Examiner Name  
Group / Art Unit  
Attorney Docket No. 28870



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- ☒ Charge Any Additional Fee Required Under 37 CFR §§ 1.16 and 1.17

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## FEE CALCULATION

### 1. BASIC FILING FEE

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
101 690	201 345	Utility filing fee	345
106 310	206 155	Design filing fee	
107 480	207 240	Plant filing fee	
108 690	208 345	Reissue filing fee	
114 150	214 75	Provisional filing fee	

SUBTOTAL (1) (\$ ) 345

### 2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
Independent Claims 5	-20** = 2	39	78
Multiple Dependent			

\*\*or number previously paid, if greater; For Reissues, see below

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description
103 18	203 9	Claims in excess of 20
102 78	202 39	Independent claims in excess of 3
104 260	204 130	Multiple dependent claim, if not paid
109 78	209 39	** Reissue independent claims over original patent
110 18	210 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$ ) 423

## FEE CALCULATION (continued)

### 3. ADDITIONAL FEES

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
105 130	205 65	Surcharge - late filing fee or oath	
127 50	227 25	Surcharge - late provisional filing fee or cover sheet	
139 130	139 130	Non-English specification	
147 2,520	147 2,520	For filing a request for reexamination	
112 920*	112 920*	Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*	Requesting publication of SIR after Examiner action	
115 110	215 55	Extension for reply within first month	
116 380	216 190	Extension for reply within second month	
117 870	217 435	Extension for reply within third month	
118 1,360	218 680	Extension for reply within fourth month	
128 1,850	228 925	Extension for reply within fifth month	
119 300	219 150	Notice of Appeal	
120 300	220 150	Filing a brief in support of an appeal	
121 260	221 130	Request for oral hearing	
138 1,510	138 1,510	Petition to institute a public use proceeding	
140 110	240 55	Petition to revive - unavoidable	
141 1,210	241 605	Petition to revive - unintentional	
142 1,210	242 605	Utility issue fee (or reissue)	
143 430	243 215	Design issue fee	
144 580	244 290	Plant issue fee	
122 130	122 130	Petitions to the Commissioner	
123 50	123 50	Petitions related to provisional applications	
126 240	126 240	Submission of Information Disclosure Stmt	
581 40	581 40	Recording each patent assignment per property (times number of properties)	
146 690	246 345	Filing a submission after final rejection (37 CFR § 1.129(a))	
149 690	249 345	For each additional invention to be examined (37 CFR § 1.129(b))	

Other fee (specify) \_\_\_\_\_

Other fee (specify) \_\_\_\_\_

Reduced by Basic Filing Fee Paid

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## SUBMITTED BY

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Signature	Date	Sept. 6, 2000

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Lambert Haner  
Title: CONTROLLED RELUCTANCE AC INDUCTION MOTOR  
Docket No: 28870

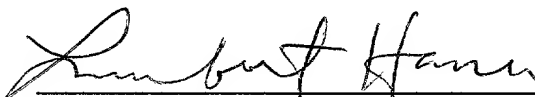
**VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS**

I hereby declare that I am an independent inventor for purposes of paying reduced fees to the Patent and Trademark Office with regard to the above-entitled invention, described in the specification filed herewith.

I have not assigned, granted, conveyed or licensed, and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person or to any concern which would not qualify as a small business concern or a non-profit organization.

I acknowledge the duty to file, in this application, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.



Lambert Haner  
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Date: SEPT. 3, 2000

## CONTROLLED RELUCTANCE AC INDUCTION MOTOR

The invention relates generally to the field of electric motors and specifically to an AC motor with improved performance characteristics.

## PRIOR ART

Many types of electric motors are known to the industry. Typically, these known motors have certain desirable characteristics such as high starting torque, variable speed and/or high power density. Often, however, a motor with desirable characteristics for a given application has certain disadvantages or deficiencies. These undesirable characteristics often include relatively high cost, electrical circuit complexity, radio frequency or electromagnetic interference, energy inefficiency, limited reliability and/or comparatively short service life.

## SUMMARY OF THE INVENTION

The invention provides an AC power operated electric motor that exhibits desirable torque/speed characteristics when operated in an open loop condition and is effectively speed and/or torque controlled with relatively simple and economical electrical circuitry. The motor has a stator with field windings that are energized with alternating current and that are arranged to induce an AC current in a conductive loop on a rotor or armature. In various configurations of the motor, the field windings comprise at least two coils angularly displaced from one another around the rotor axis. The positions of the windings in some configurations represent physically or mechanically distinct phases.

1       The AC stator field is caused to move about the axis of  
2 the rotor and the induced AC field in the conductive loop  
3 produces a torque on the rotor causing it to rotate in  
4 synchronization with the field rotation. The rotation of  
5 the stator field is produced by switching or appropriately  
6 modulating AC power to successive angularly displaced field  
7 coils.

8       The motor can be arranged with 2, 4, 6 or even a  
9 greater number of even poles and with as many field winding  
10 phases as suitable for a particular application. Motor  
11 torque, and therefore power, is multiplied in proportion to  
12 the number of poles provided in the motor. The motor has  
13 open loop speed/torque characteristics approaching the  
14 desirable ideal of constant horsepower. These  
15 characteristics include high starting torque and high speed  
16 at low load.

17       Importantly, the motor lends itself to relatively  
18 simple and energy efficient speed control and/or torque  
19 control. A standard speed control over a 10:1 ratio is  
20 readily achieved. Rated torque can be achieved at zero  
21 speed with proper circuitry and therefore the speed range  
22 can be from zero to the maximum rated speed. Some of the  
23 additional advantages of the motor include low stall  
24 current, operation on simple square wave power without  
25 difficulty with harmonics, and increased power and/or torque  
26 for a given physical size motor as compared to conventional  
27 induction motors, for example.

28                   BRIEF DESCRIPTION OF THE DRAWINGS

29       FIG. 1 is a schematic perspective view of a motor  
30 illustrating principles of the invention;

1        FIG. 2 is a generalized graph illustrating the  
2 relationship of torque versus rotor deflection angle for  
3 motors constructed in accordance with the invention;

4        FIG. 3 is a schematic perspective view of a motor  
5 constructed in accordance with the invention;

6        FIG. 4 is an electrical circuit diagram of a controller  
7 for the motor of FIG. 3;

8        FIG. 5 is a generalized graph illustrating the  
9 relationship of speed versus torque of a motor constructed  
10 in accordance with the invention;

11       FIG. 6A is a diagram of square wave power available  
12 from an inverter illustrated in FIG. 7;

13       FIG. 6B is a diagram of a modified square wave power  
14 signal produced by the circuit of FIG. 7;

15       FIG. 7 is a circuit diagram for controlling the speed  
16 of the motor of FIG. 3;

17       FIGS. 8A through 8D are diagrammatic representations of  
18 signals developed in the circuit of FIG. 7;

19       FIG. 9 is a diagrammatic illustration of a system for  
20 controlling the speed of a motor constructed in accordance  
21 with the invention;

22       FIG. 10 is a schematic illustration of a motor arranged  
23 for speed control by the control system of FIG. 9;

24       FIG. 11 is an alternative circuit for driving the motor  
25 of FIG. 3;

26       FIG. 12 is a schematic representation of a motor of the  
27 invention having field windings arranged in quadrature;

28       FIG. 13 is a circuit for driving the motor of FIG. 12;

29       FIG. 14 is a schematic perspective view of a four pole  
30 three-phase motor constructed in accordance with the  
31 invention; and

1        FIG. 15 is a diagrammatic illustration of the field  
2        vectors of one of the windings of the motor of FIG. 14.

3                    DESCRIPTION OF THE PREFERRED EMBODIMENTS

4        Referring now to FIG. 1, a motor 10 has a stator 11  
5        with a field winding 12 and a rotor or armature 14 supported  
6        by suitable bearing structure for rotation about an axis 16.  
7        The winding 12 is arranged in two sections or portions 12a,  
8        12b on diametrically opposite sides of the rotor 14. The  
9        rotor 14 has a conductive loop 17 that has two diametrically  
10       opposite portions 18 near the periphery of the rotor that  
11       extend parallel to the rotor axis 16 and two end portions  
12       19. A main body 21 of the rotor 14 can be constructed of  
13       suitable magnetic silicon steel laminations in a manner  
14       known in the art. The two loop portions 18 that extend  
15       longitudinally of the rotor lie in a common plane that  
16       passes through the rotor axis 16. For purposes of this  
17       disclosure, the plane of the conductive loop 17 is taken as  
18       the plane of the conductor portions 18. The conductive loop  
19       17, which can be made of copper or aluminum, for example, is  
20       electrically continuous; the end portions 19 shunt the  
21       longitudinal portions 18. The stator 11 has its field  
22       windings 12a, 12b wound about suitable magnetic material  
23       such as a stack of magnetic silicon steel laminations 22a  
24       and b.

25        When the field coil or winding 12 is energized with an  
26        AC voltage, a magnetic field is created with a vector that  
27        is parallel to an axis 23 extending between the windings  
28        12a, b. With the field coil 12 thus energized with an AC  
29        voltage, when the rotor 14 is displaced from the illustrated  
30        solid line position through an angle  $\psi$  magnetic field  
31        conditions urge the rotor 14 to return to the solid line

1 position where the plane of the conductive loop 17 is  
 2 aligned with the field axis 23. That is, the magnetic field  
 3 conditions urge the rotor 14 to the position where the angle  
 4  $\psi$  is 0.

5 FIG. 2 is a generalized diagram of the relationship  
 6 between torque and angular displacement  $\psi$ . The diagram  
 7 shows that the torque tending to move the rotor 14 towards  
 8 the position of alignment with the axis 23 increases  
 9 proportionately with the displacement or angle  $\psi$ . Torque  
 10 reaches a maximum value at about  $70^\circ$ ; at displacements  
 11 beyond this, the torque diminishes. At  $\psi$  equal to  $90^\circ$ , i.e.  
 12 when the plane of the conductive loop 17 is transverse to  
 13 the direction of the field vector of the winding 12, the  
 14 torque reduces to 0. This  $\psi = 90^\circ$  position can be called a  
 15 hard neutral while the position at  $\psi$  equal to 0 can be  
 16 called a soft neutral.

17 When the plane of the conductive loop 17 is turned from  
 18 alignment with the field vector of the stator 11, i.e.  $\psi$  not  
 19 equal to 0, the AC magnetic field produced by the winding 12  
 20 induces an AC current in the conductive loop 17. This rotor  
 21 current produces its own magnetic field which opposes the  
 22 stator field. The opposing field produced by the conductive  
 23 loop 17 increases the reluctance of the flux path of the  
 24 stator field. It can be shown that in an electromechanical  
 25 system, such as the motor 10 illustrated in FIG. 1, physical  
 26 laws work to reduce the reluctance in the system.  
 27 Consequently, the motor 10 behaves as discussed with the  
 28 rotor 14 being urged to a position where the plane of the  
 29 conductive loop 17 is aligned with the axes 23 and the  
 30 reluctance of the motor system being reduced.

31 The motor 10 of FIG. 1, as so far described, is not  
 32 practical as a general purpose rotating motor since it



1 cannot sustain continuous rotation of the rotor. However,  
2 the motor's characteristics, as described, are helpful in  
3 understanding the operation of other motors, constructed in  
4 accordance with the invention, such as those described  
5 hereinbelow.

6 FIG. 3 diagrammatically shows a motor 26 that applies  
7 the foregoing principles in a two pole rotor 14, like that  
8 described with reference to FIG. 1, but with a three phase  
9 stator 28. (The "two pole" designation pertains to the  
10 rotor or armature and derives from north and south magnetic  
11 poles produced by the conductive loop 17 when the loop is in  
12 an AC magnetic field.) The stator 28 typically includes a  
13 body formed by a stack of laminations of suitable magnetic  
14 silicon steel with internal axially oriented slots 30  
15 distributed about the periphery of the rotor 14 as is  
16 generally conventional in motor construction. A winding A  
17 has turns wrapped axially around the rotor. The turns  
18 include longitudinal or axially oriented portions disposed  
19 in the lamination slots 30 on diametrically opposite sides  
20 of the rotor 14 and end portions circumferentially looped  
21 around the axial projection of the rotor in a manner known  
22 in the motor art. The longitudinal portions of the turns of  
23 the winding A are geometrically centered on a plane  
24 represented at 31 that passes through the rotor axis 16.  
25 For clarity, only the winding A is illustrated in FIG. 3 and  
26 it will be understood that the other windings B and C are  
27 similar in construction. The planes of the windings A, B  
28 and C are oriented at  $120^\circ$  relative to one another with  
29 reference to the axis 14 of rotation of the rotor 14 and  
30 pass through this axis so that adjacent portions of the  
31 windings A, B and C are centered at  $60^\circ$  intervals. The  
32 winding A, when energized with AC power develops an AC

1 magnetic field vector 32 in a plane 33 perpendicular to the  
2 plane 31 of the winding A. The other windings B, C,  
3 similarly, produce AC magnetic field vectors perpendicular  
4 to their respective planes. The windings A, B and C are  
5 thus in a physical or mechanical phase relationship to one  
6 another and are electrically isolated from one another. By  
7 switching or modulating AC power sequentially to the  
8 mechanically phased windings A, B and C, the rotor 14 will  
9 be driven in rotation. As explained hereinabove, the rotor  
10 14 will tend to align itself with the field vector of an  
11 energized winding (or as discussed later the resultant field  
12 vector of simultaneously energized field windings). When  
13 the plane of the rotor conductive loop 17 approaches the  
14 vector of the field from one energized winding, that winding  
15 is de-energized while the adjacent winding in the direction  
16 of rotor rotation is energized. By continuing this field  
17 switching process, the rotor 14 is caused to rotate  
18 continuously.

19 FIG. 4 illustrates an example of a circuit or  
20 controller 36 suitable for driving the two pole, three  
21 winding phase motor 26 of FIG. 3. The motor windings are  
22 represented as A, B and C in the circuit of FIG. 4. In the  
23 circuit, commercial power, e.g. 60 Hz, 110 volt, single  
24 phase power is connected to lines 37, 38. This power is  
25 converted to DC in a rectifier and voltage doubler circuit  
26 comprising a pair of diodes 39, 41 and capacitors 42, 43.  
27 Positive and negative voltages are developed on respective  
28 lines or busses 46, 47.

29 Square wave AC power is supplied independently to each  
30 winding A, B or C from paired power mosfet switches 51, 52  
31 associated with each winding. One of the mosfet switches 51  
32 supplies positive voltage while the other 52 supplies

1 negative voltage thereby producing an AC power signal. The  
2 mosfet switches 51, 52 are driven by an associated  
3 integrated circuit 53 (such as an IR 2104). These drivers  
4 53 are powered by a suitable 12 volt DC source. Each driver  
5 53 alternately operates the associated mosfets 51, 52 at a  
6 frequency imposed by a frequency generator 54 (such as an  
7 MCI 4046) signalling from its output (pin 4) to an input  
8 (pin 2) of each driver 53. The frequency can be any  
9 suitable frequency, preferably higher than commercial power  
10 of 60 or 50 Hz. A typical frequency can be between 100 to  
11 250 Hz but can be higher if design parameters require such  
12 and appropriate materials are used.

13 A shaft encoder 56 (FIG. 3) of any suitable type and  
14 preferably a non-contact type monitors the angular position  
15 of the rotor 27 and, therefore, the plane of the conductive  
16 loop 17. In the illustrated example of FIG. 3, the shaft  
17 encoder 56 senses when a 60° arc on a drum rotating with the  
18 rotor 14 associated with each winding A, B or C passes the  
19 reference point of a non-rotating part 59 of the encoder  
20 fixed relative to the stator 28. The drum 57 of the encoder  
21 56 is divided into three channels, each channel  
22 corresponding to one of the field windings A, B or C. The  
23 encoder 56 signals the driver 53 of a particular field  
24 winding A, B or C when an angular sector on the drum 57  
25 associated with that particular winding is in proximity to  
26 the non-rotating part 59 of the encoder. The encoder 56  
27 maintains the signal to the appropriate driver 53 for a time  
28 in which a field winding A, B or C develops a relatively  
29 large torque on the rotor. This period will be, roughly  
30 when the plane of the conductive loop 17 is between 75 and  
31 15° out of alignment with the magnetic field vector of a  
32 particular winding (i.e.  $75^\circ \geq \psi \geq 15^\circ$ ).

1       The time period or, more properly, the angular duration  
2 of energization of a particular field A, B or C can be set  
3 by the geometry of the codes on the drum 57 of the encoder  
4 56. The drum 57 may be encoded with arcs of detectable  
5 material that have a dwell of 60°. This geometry allows  
6 each winding, where there are three windings, to be  
7 energized twice for each revolution of the rotor 14. While  
8 a driver 53 is enabled (i.e. turned on) from a channel of  
9 the encoder 56, the driver cycles the associated mosfet  
10 switches 51, 52 on and off at the frequency produced by the  
11 frequency generator 54. The mosfet switches 51, 52 thereby  
12 apply a square wave AC power signal, at the frequency of the  
13 generator 54, to the associated field winding A, B or C.  
14 With the circuit of FIG. 4 when one of the windings A, B or  
15 C is energized the other two windings are inactive.

16       The motor 26 of FIG. 3, driven by the open loop circuit  
17 36 of FIG. 4 has a desirable speed torque curve  
18 schematically illustrated in FIG. 5. It will be seen that  
19 the motor 26 approaches a constant horsepower device.  
20 Additionally, the motor 26 is characterized by relatively  
21 high starting torque and is capable of relatively high speed  
22 operation. A motor operating with the principles of the  
23 motor 26 discussed in connection with FIGS. 3 and 4 can be  
24 constructed with more field windings or field phases. The  
25 windings, typically, can be evenly spaced around the stator  
26 and suitable corresponding additional driver circuits and a  
27 modified shaft encoder can be employed. Such a motor has  
28 the advantage of less torque ripple than that of the  
29 illustrated three phase motor 26.

30       The speed of the motor 26 and like motors can be  
31 controlled by either controlling the power delivered to the  
32 motor or by controlling the position of the shaft encoder

1 signals relative to the stator. Each method can have many  
2 variations. Controlling the power to the motor may be  
3 implemented very simply, but such control may not  
4 necessarily produce the best efficiency over a wide speed  
5 range. Controlling the relative positions of the encoder  
6 signals may produce better efficiency, but may be more  
7 complex in circuit implementation for certain applications.  
8 In some applications, a combination of both methods may be  
9 useful.

10 One way of controlling power for speed control is to  
11 control the width of each 1/2 cycle of a voltage square wave  
12 delivered to the motor. Full power of the square wave is  
13 applied when each half cycle occupies the total time of one  
14 half period as depicted in FIG. 6A. If the beginning of  
15 each half cycle is delayed by some fraction of the half  
16 period, as depicted in FIG. 6B, then the total amount of  
17 power delivered to the motor is reduced. The motor is not  
18 sensitive to waveform (does not need sine waves) so that  
19 only the total energy per half cycle is significant. There  
20 are many ways to implement this kind of control; a simple  
21 version is shown in FIG. 7. This circuit is used in  
22 conjunction with the circuit of FIG. 4. The frequency  
23 generator 54 is redrawn here. As will be understood from  
24 the following discussion, the circuit of FIG. 7 is  
25 interposed in the lines from the encoder 56 to the drives 53  
26 for the field windings A, B and C. The frequency signal  
27 output of the frequency generator 54 is fed into pin 2 of IC  
28 12 which is a four stage binary counter. Each stage divides  
29 the frequency by 2. At pin 6 of IC 12 (the output of the  
30 4th stage), the frequency is 1/16 of the input at pin 2.  
31 The output frequency at pin 6 is fed into the driver stages  
32 53 (at pin 2) of each power mosfet switch 51, 52 (FIG. 4)

1 that delivers power to a particular stator winding phase or  
2 coil A, B or C. In this arrangement, the frequency  
3 generator 54 is typically set to a frequency that is 16  
4 times greater than what is used in the original circuit in  
5 FIG. 4. The binary outputs from the other three stages are  
6 connected to a summing resistor network 61 at the input of  
7 an operational amplifier designated as IC 13 at pin 2. The  
8 output signal at pin 1 of IC 13 will appear as a sawtooth  
9 waveform and will be related to the square wave output on  
10 pin 6 of IC 12 as shown in FIGS. 8A and 8B, respectively.

11 A speed command signal and a speed feedback signal  
12 (e.g. derived from the shaft encoder) are summed  
13 algebraically at pin 9 of IC 13 and the difference (speed  
14 error signal) is produced at pin 8 of IC 13. At pin 14 of  
15 IC 13 is the polarity inversion of the error signal. The  
16 error signal is then compared with the sawtooth waveform by  
17 the comparator circuit composed of pins 6, 5 and 7 of IC 13.  
18 With reference to FIG. 8C, when the magnitude of the error  
19 signal is below the sawtooth level, the output of pin 7 is  
20 0; when the magnitude of the error signal is above the  
21 sawtooth level, the output of pin 7 is positive (a logic  
22 "1"). This output signal modulates the encoder signals that  
23 feed into the power mosfet drivers 53. In essence, the  
24 signal controls the turn on of each driver 53 at its pin 3.  
25 This is accomplished by dual input "and" gates shown as IC  
26 14 (MC 14081B). Signals from the encoder 56 feed into one  
27 gate input and the signal from pin 7 of IC 13 feeds into the  
28 second gate input. The output of each gate IC 14 then feeds  
29 into the pin 3 of a respective driver 53. The result is a  
30 power signal applied to the motor field windings A, B or C  
31 as shown in FIG. 6D. As the speed error signal varies in  
32 magnitude, the width of each half cycle will vary in

1 accordance. Where the power is supplied as a sine wave,  
2 such as from commercial power, a speed control circuit can  
3 be arranged to eliminate the beginning of each half cycle,  
4 typically in the manner an SCR is regularly used in like  
5 service.

6 The second method that can be used for speed control is  
7 to shift the encoder signals to different phase or winding  
8 drivers in accordance to the magnitude of the speed error  
9 signal. FIG. 9 illustrates circuitry to accomplish this.  
10 The select signal is derived from the speed control error  
11 signal.

12 A motor 62 schematically shown in FIG. 10 has eight  
13 field windings (a - h) and, accordingly, eight driver  
14 circuits (corresponding to elements 53, 51 and 52 in FIG.  
15 4). The field windings a - h are like the windings A, B and  
16 C in FIG. 3. If a shaft position encoder or sensor 63 has  
17 its signals directed to turn on the field coils which  
18 produce the maximum torque, then the motor speed will  
19 increase to the point where the load torque is equal to the  
20 produced or developed motor torque. To reduce the torque  
21 and lower the speed, it is necessary to direct the signals  
22 of the position encoder 63 to different field coils. Speed  
23 control can thus be obtained by switching the encoder  
24 signals to different coils in response to the speed control  
25 error signal. The plane of the armature conductive loop 17  
26 is shown in relationship to the field coil position labelled  
27 a - h. If coil a is energized, maximum torque is generated  
28 in the counter-clockwise direction. A magnetic field vector  
29 64 of winding a is perpendicular to the plane of winding a.  
30 If field coil b were energized, a lesser torque would be  
31 created, and if field coil c were energized, an even lesser  
32 torque would be developed. By shifting the encoder

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1 connection to energize different coils, the torque is  
2 controlled. By using the speed error signal to determine  
3 the switching, the motor speed can be regulated. The speed  
4 error signal magnitude is compared to fixed signal voltage  
5 levels that are stepped by fixed increments. When the speed  
6 error exceeds each fixed level, a new connection arrangement  
7 is made between the encoder and the field coils. For  
8 example, with eight field coils, suppose that at the maximum  
9 level, encoder output A controls coil a and encoder B  
10 controls coil b, etc. Then, when the error signal drops to  
11 the next level, a logic switching action takes place in a  
12 multiplex gate 63 (FIG. 9) to connect encoder output A to  
13 coil b, and encoder output B to coil c, encoder C to coil d,  
14 etc. Then, when the error signal drops to the next level  
15 down (third level), the logic switching action connects  
16 encoder output A to coil c, and encoder output B to coil d,  
17 encoder output C to coil e, etc. Thus, the control acts to  
18 shift the position of the encoder signals in proportion to  
19 the magnitude of the error signal. This action will then  
20 increase or decrease torque and, accordingly, increase or  
21 decrease speed.

22 FIG. 11 shows an alternative controller or circuit 70,  
23 of simplified design, for operating the motor 26. Single  
24 phase alternating current power such as 110 volt 60 Hz  
25 commercial power is supplied to the windings A, B and C  
26 through corresponding triacs 71 or other electrically  
27 controllable switches. A frequency generator 73, (MCI 4046)  
28 produces a series of pulses having a frequency that is  
29 proportional to the voltage set by a potentiometer 72. The  
30 pulses are input to a counter 74 such as a CMOS 4017. The  
31 three outputs of the counter 74 are applied to sequentially  
32 fire the triacs 71 through a buffer 76 such as a CMOS 4049



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1 inverting buffer that feeds the opto isolator trigger to  
2 each triac. The counter 74 assures that the windings or  
3 phases A, B and C are triggered sequentially at a rate  
4 corresponding to the frequency set by the voltage at the  
5 potentiometer 72. The motor 26, when operated by the  
6 circuit of FIG. 11, will run at a speed synchronous with the  
7 rate that the field windings A, B and C are triggered. The  
8 circuit 70 with the adjustable potentiometer 72 and variable  
9 frequency of the generator 73 thus provides a simple method  
10 of speed control for the motor 26. As this circuit 70 of  
11 FIG. 11 suggests, the motor 26 and others constructed like  
12 it in accordance with the invention can be operated directly  
13 off a commercial single phase power supply such as, for  
14 example, 120 volt 60Hz power where high speed operation is  
15 not required. Conversely, this motor 26 and the circuit 70  
16 can be supplied with a higher frequency power supply where  
17 it is desired to operate the motor at higher speeds.  
18 Innumerable other control systems and circuits are suitable  
19 for operating a motor constructed in accordance with the  
20 invention as will be apparent from an understanding of the  
21 present disclosure.

22 A flux vector drive is also contemplated for the motor  
23 of the invention. Referring to FIG. 12, a simple field  
24 winding configuration for a two winding two pole motor 80 is  
25 shown. Stator field or phase windings X, Y are physically  
26 located in quadrature and labelled X and Y to correspond  
27 with x and y axes. The windings X, Y create magnetic flux  
28 vectors along the corresponding x and y axes. Currents  
29 flowing through both sets of windings X and Y create a  
30 magnetic field flux vector 81 which is the vector sum of the  
31 individual magnetic flux vectors created by the currents in  
32 the separate windings X, Y. A vector angle  $\theta$  of the vector

1 varies with respect to the X axis depending on respective  
2 magnitudes of the currents in windings X, Y.

3 The magnitudes of the AC currents in the windings X, Y  
4 are:

$$5 \quad I_x = \cos\theta \sin 2\pi f_c t; \text{ and}$$

$$6 \quad I_y = \sin\theta \sin 2\pi f_c t;$$

7 where  $f_c$  is the frequency of the current supplied, such as  
8 60 Hz. The field flux vector 81 represents an alternating  
9 magnetic field with the frequency  $f_c$ . The field flux vector  
10 81 can be positioned at any angle  $\theta$  by varying the currents  
11 in the field windings X, Y according to the following  
12 relationship:

$$13 \quad \theta = \sin^{-1} \left( \frac{I_y}{\sqrt{I_x^2 + I_y^2}} \right)$$

14  
15  
16 The motor 80 has a rotor 14 like that described in  
17 connection with FIG. 1; the plane of the conductive loop 17  
18 is displaced from the X axis by a rotor angle  $\phi$ . The rotor  
19 14 rotates synchronously at the speed that the field vector  
20 81 is rotated. As discussed below, the field windings can  
21 be supplied with modulated AC currents from power amplifiers  
22 operated by a signal processor to appropriately rotate the  
23 magnetic field vector 81.

24 By creating and controlling a difference between the  
25 field flux vector angle  $\theta$  and the rotor angle  $\phi$ , the torque  
26 output of the motor 80 can be controlled. That is, the  
27 torque is controlled by controlling the relative positions  
28 of the field flux vector and the plane of the conductive  
29 loop 17 on the rotor 14. As discussed previously with  
30 reference to FIG. 2, torque is developed when the rotor or  
31 armature 14 is located where there is an angular deflection  
32  $\psi$  between the plane of the conductive loop 17 and the flux

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1 vector between the winding portions 12a, b; this torque  
 2 varies with the magnitude of the angle  $\psi$ . Similarly, in  
 3 FIG. 12, the torque varies with the difference between the  
 4 flux vector angle  $\theta$  and the rotor angle  $\phi$ . Note the  
 5 relationship  $\psi = \theta - \phi$ .

6 As previously discussed, the vector angle  $\theta$  is varied  
 7 by varying the current amplitudes in the field windings X,  
 8 Y. Since the currents are AC, the field currents will be  
 9 suppressed carrier amplitude modulated sine waves that can  
 10 be represented as:

$$11 \quad I_x = \cos(\omega_r t \pm \psi) \sin 2\pi f_c t ; \text{ and}$$

$$12 \quad I_y = \sin(\omega_r t \pm \psi) \sin 2\pi f_c t ;$$

13 where  $\omega_r$  is the rotational speed of the rotor 14. The  
 14 angular deflection  $\psi$  with respect to the field flux vector  
 15 is determined by the respective field currents  $I_x$ ,  $I_y$  and  
 16 the angular velocity  $\omega_r$ :

$$17 \quad \pm \psi = \sin^{-1} \left( \frac{I_y}{\sqrt{I_x^2 + I_y^2}} \right) - \omega_r t$$

18  
 19  
 20 Referencing FIG. 2, the deflection angle  $\psi$  is varied to  
 21 achieve the desired torque characteristics by varying the  
 22 currents  $I_x$ ,  $I_y$ . The rotor position  $\phi$  is sensed, for  
 23 example, by a transducer or electrical parameters. Rotor  
 24 position information is used to control the flux vector  
 25 position  $\theta$  to maintain the desired deflection  $\psi$  and,  
 26 therefore, the motor torque.

27 A flux vector control circuit 85 that applies the  
 28 foregoing principles and relationships of field current,  
 29 field vector and rotor angle for torque control is shown in  
 30 FIG. 13. The control 85 includes a signal processor 86 with  
 31 two outputs for generating the currents  $I_x$ ,  $I_y$ . The  
 32 currents are fed through respective power amplifiers 87 to

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1 the field windings X, Y. Frequency  $F_c$  is set by a suitable  
 2 frequency input. A rotor position sensor 89, such as a  
 3 numerical shaft position sensor, provides rotor position  
 4 information data to the signal processor 86. A torque  
 5 command input, corresponding to a deflection angle  $\psi$  is  
 6 provided to the signal processor to control torque. The  
 7 signal processor 86 in accordance with the foregoing  
 8 formulas generates the currents  $I_x$ ,  $I_y$  as functions of the  
 9 frequency  $F_c$ , rotor position  $\phi$  (which indicates rotor speed  
 10  $\omega_r$ ), and torque command deflection angle  $\psi$  to control the  
 11 torque characteristics of the motor 80. The speed of the  
 12 motor is controlled according to the rate  $\omega$  at which the  
 13 carrier signal is modulated, which can be selected by a  
 14 speed input. The rotor position sensor can be connected to  
 15 provide speed or position feedback, diagrammatically  
 16 represented at 88, through a torque control 84 to control  
 17 the torque command angle setting  $\psi$ .

18 A motor constructed in accordance with the invention  
 19 can be made with four poles as schematically shown in FIG.  
 20 14. The motor 90 can develop twice the torque of a  
 21 similarly sized two pole motor such as the motor 26 in FIG.  
 22 3. The illustrated motor 90 has three field winding phases  
 23 designated Phase A, Phase B and Phase C. Each Phase A, B  
 24 and C has four coils 91, 92, 93, and 94. Each of these  
 25 coils has a pair of spaced axially extending portions 96 and  
 26 a pair of end turn portions 97, one at each end of a stator  
 27 typically of suitable laminations represented by the  
 28 circular line 98. The coils 91, 92, 93 and 94 are connected  
 29 in series with alternate coils wound in a clockwise  
 30 direction and intervening coils wound in counter-clockwise  
 31 direction. Alternatively, the coils 91 - 94 can be  
 32 connected in parallel. For clarity, the coils 91 - 94 of

1 only one phase (A) is shown, it being understood that the  
2 other phases B and C are identical. A rotor 99 of the motor  
3 90 has four conductive wires or rods 100 equally spaced  
4 around the circumference of the rotor 99 and extending  
5 longitudinally of the rotor. The conductors 100 are  
6 interconnected or shunted by end wires or conductors 101 at  
7 each end of each conductor 100. The longitudinal conductors  
8 100, like the conductors 17 of the rotor 14 of FIG. 3, are  
9 parallel with the axis of rotation of the rotor 99 on a  
10 shaft 95. The rotor 99 and stator 98 typically include  
11 bodies formed of silicon steel laminations as previously  
12 described. The windings of Phases A, B and C can be  
13 energized by a circuit like that shown in FIGS. 4 or 11.  
14 Motors having a greater even number of poles such as 6, 8 or  
15 more, can be constructed similarly to the four pole motor of  
16 FIG. 14 and such motors will have a proportionately higher  
17 torque capacity.

18 As will be understood from the foregoing disclosure,  
19 the motor of the invention can take various forms and can be  
20 powered by innumerable electrical circuit arrangements, both  
21 open and closed loop. Switches for the field windings can  
22 include triacs, transistors, silicon controlled rectifiers  
23 (SCR's) and magnetic amplifiers, for example. The rotor,  
24 rather than having a conductive loop to present a variable  
25 reluctance to the stator field, can be formed with a  
26 diametrically disposed air gap or a conductive plate in the  
27 plane otherwise occupied by the conductive rotor loop. The  
28 rotor can be disposed around, rather than in, the stator.  
29 The conductive loop or loops on the rotor can be skewed in a  
30 helical or like sense to reduce torque ripple. The number  
31 of field windings and related electronic switches, also, can  
32 be increased to decrease torque ripple. Some of the turns

1 of a particular winding can share the same stator lamination  
2 slot or angular position as some of the winding turns of an  
3 adjacent winding.

4 The motor can be supplied with a shaft encoder and  
5 appropriate circuitry for operation as a stepping motor and  
6 is especially suitable for large size stepping motors. A  
7 desired angular resolution for a stepping motor application  
8 can be achieved by providing a suitable number of field  
9 windings. As previously discussed herein, the rotor will  
10 seek to align the plane of the conductive loop, or  
11 equivalent structure, to the magnetic field vector of a  
12 particular winding that is energized. The motor is  
13 reversible simply by reversing the sequence that the field  
14 windings are energized by the related circuitry.

15 A circuit powering the field windings of the motor can  
16 energize more than one field winding at a time to reduce  
17 torque ripple and/or the circuit can be arranged to modulate  
18 power to the windings rather than simply turning them on and  
19 off. Field windings on the stator can have various  
20 configurations besides those illustrated in FIGS. 1, 3 and  
21 14, it being important that the winding arrangement be  
22 capable of producing an AC magnetic field in the space of  
23 the rotor that moves around the axis of the rotor.

24 While the invention has been shown and described with  
25 respect to particular embodiments thereof, this is for the  
26 purpose of illustration rather than limitation, and other  
27 variations and modifications of the specific embodiments  
28 herein shown and described will be apparent to those skilled  
29 in the art all within the intended spirit and scope of the  
30 invention. Accordingly, the patent is not to be limited in  
31 scope and effect to the specific embodiments herein shown  
32 and described nor in any other way that is inconsistent with

- 1 the extent to which the progress in the art has been  
2 advanced by the invention.

## WHAT IS CLAIMED IS:

1           1. An AC electric motor comprising a stator and a  
2 rotor journalled for rotation about an axis relative to the  
3 stator, the rotor having an electrically continuous  
4 conductive loop, the loop having longitudinal portions  
5 spaced from and generally parallel to the axis and shunt  
6 portions extending between the ends of the longitudinal  
7 portions, the stator having at least two separate windings  
8 angularly displaced from one another about the axis of the  
9 rotor, an electrical circuit for selectively energizing and  
10 de-energizing the field windings with separate AC currents  
11 to develop an AC magnetic field vector that moves around the  
12 rotor axis, the field windings and conductive loop being  
13 arranged so that the AC magnetic field vector induces an AC  
14 current in the conductive loop and the reluctance of the  
15 loop operates to develop torque on the rotor that tends to  
16 cause it to rotate in synchronization with the movement of  
17 the magnetic field vector.

1           2. An electric motor as set forth in claim 1, wherein  
2 the field windings comprise 3 or more coils distributed  
3 about the rotor axis.

1           3. An AC motor as set forth in claim 2, including a  
2 circuit arranged to energize successive ones of said  
3 windings in a constant angular direction around said rotor  
4 axis while de-energizing angularly preceding ones of said  
5 windings.



1           4. An AC motor as set forth in claim 3, wherein said  
2 circuit provides an AC square wave for powering said  
3 windings.

1           5. An AC motor as set forth in claim 3, wherein said  
2 circuit is arranged to provide an AC voltage waveform and to  
3 change the characteristics of said waveform to vary the  
4 speed or torque of the motor.

1           6. An AC motor as set forth in claim 1, wherein said  
2 field windings comprise first and second windings, said  
3 second winding being oriented to produce a magnetic field  
4 vector at right angles to the magnetic field vector of the  
5 first winding, said electric circuit being arranged to  
6 modulate the currents in said windings to produce a  
7 resultant magnetic field vector that is positioned about the  
8 axis of the rotor.

1           7. An AC motor as set forth in claim 1, wherein said  
2 circuit is arranged to control the position of the magnetic  
3 field vector in relation to the rotor to regulate speed or  
4 torque.

1           8. An AC motor as set forth in claim 1, wherein the  
2 rotor has a plurality of pairs of conductive loops and the  
3 windings are arranged to produce magnetic field vectors that  
4 pass through the space of the rotor in chordal-like zones.

1           9. An electric motor comprising a stator and a rotor,  
2 field windings on the stator for producing an AC magnetic  
3 field with a vector at successive angular positions around  
4 the axis of rotation of the motor when the windings are

5 successively energized with single phase AC power, the rotor  
6 having a construction by which it increases the reluctance  
7 in the magnetic field when it has an angular orientation out  
8 of alignment with the magnetic field vector compared to its  
9 reluctance when it is aligned with the magnetic field vector  
10 whereby the rotor seeks to rotate in synchronization with  
11 the magnetic field vector produced by the field windings.

1 10. A controller circuit for an AC motor comprising a  
2 plurality of switches and/or amplifiers that generate  
3 separate power signals at respective outputs, each power  
4 signal having an AC frequency common with the other signals,  
5 the signals varying in amplitude in a cyclic manner  
6 corresponding to the speed of rotation of the rotor of the  
7 motor.

1 11. A method of operating an electric motor having a  
2 stator and a rotor which includes causing an AC magnetic  
3 field vector to be displaced around the axis of the rotor by  
4 sequentially energizing field windings on the stator and  
5 providing the rotor with a construction that has a variable  
6 reluctance in the magnetic field whereby the rotor turns  
7 with the movement of the magnetic field vector because its  
8 reluctance in the magnetic field decreases when it is  
9 aligned in a particular orientation with the magnetic field  
10 vector.

1 12. A method of converting electrical energy to  
2 mechanical energy comprising the steps of assembling a rotor  
3 and stator in a manner enabling the rotor to rotate about an  
4 axis relative to the stator, providing field windings on the  
5 stator capable of producing an AC magnetic field vector in

6 the rotor, providing the rotor with a reluctance that varies  
7 with its angular orientation relative to the AC magnetic  
8 field vector produced by field windings, energizing the  
9 field windings with AC current in a manner that causes an AC  
10 magnetic field vector to move around the axis of the rotor  
11 and thereby cause the rotor to rotate in synchronization  
12 with the movement of the AC magnetic field vector around the  
13 axis.

1 13. A method as set forth in claim 12, wherein the  
2 rotor is constructed with at least one conductive loop that  
3 includes diametrically opposed axially extending portions  
4 adjacent the periphery of the rotor so that the AC magnetic  
5 field vector is able to induce an AC current in the loop  
6 when a plane defined by said axially extending portions is  
7 at an angle relative to the AC magnetic field vector.

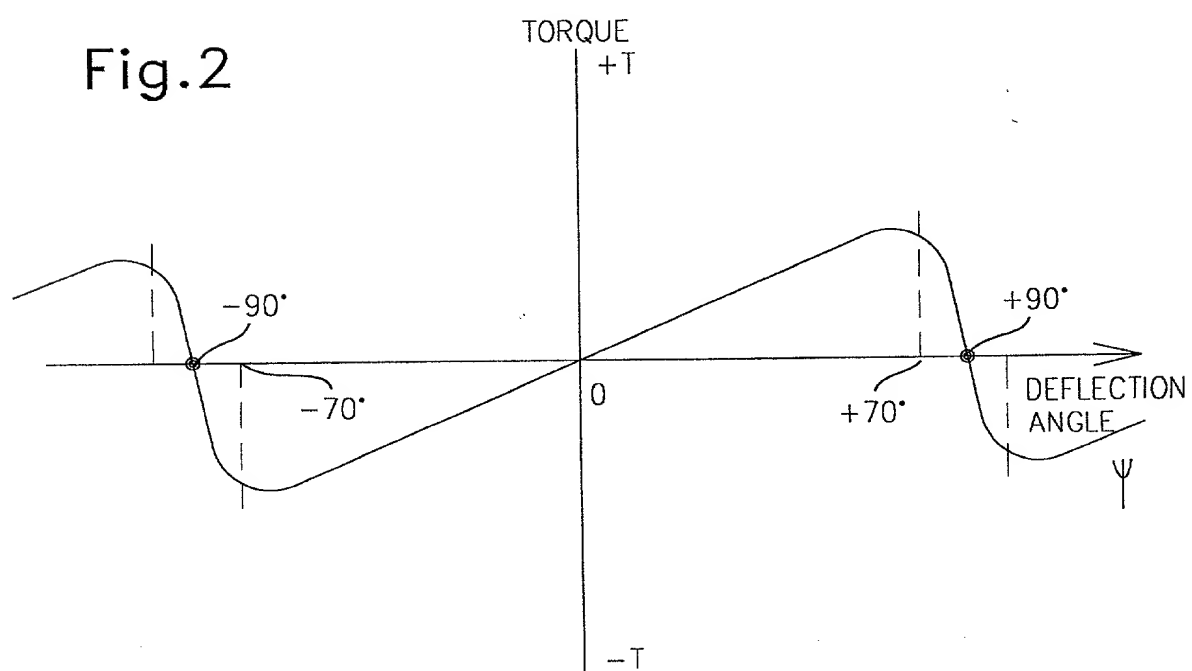
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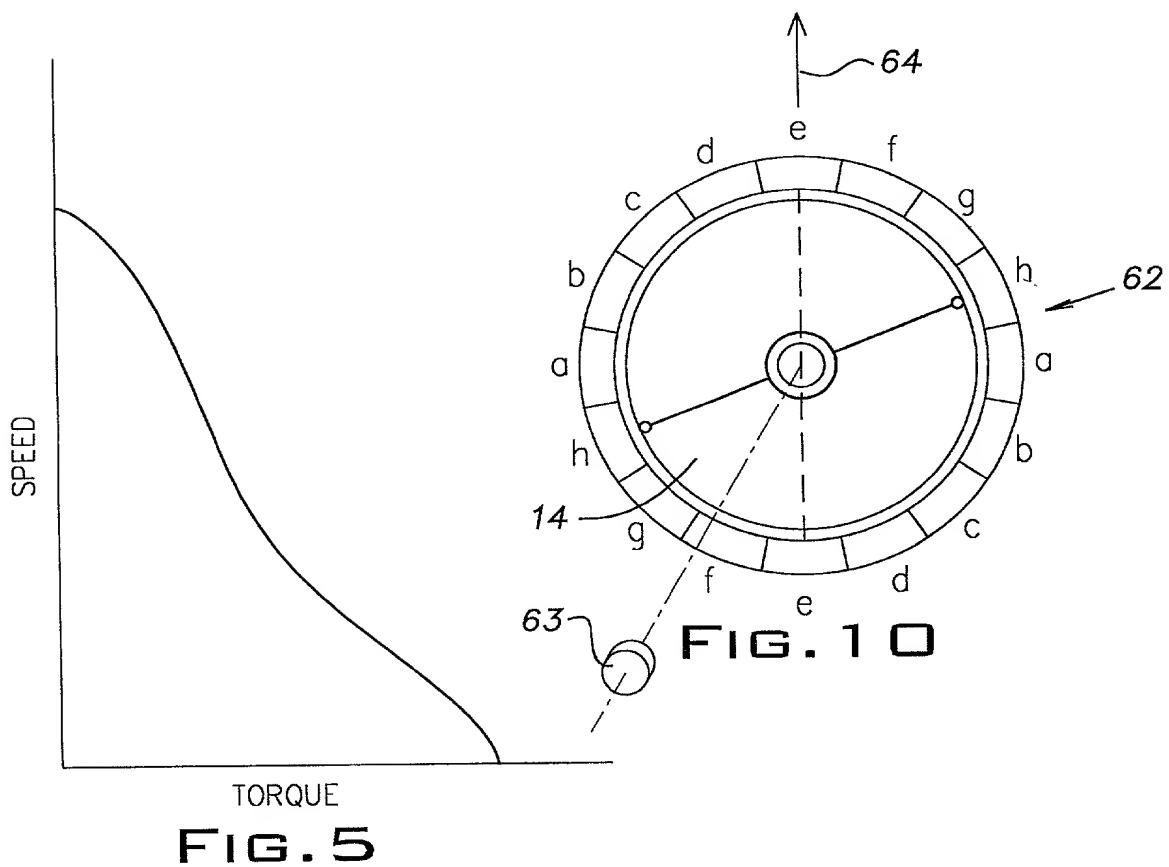
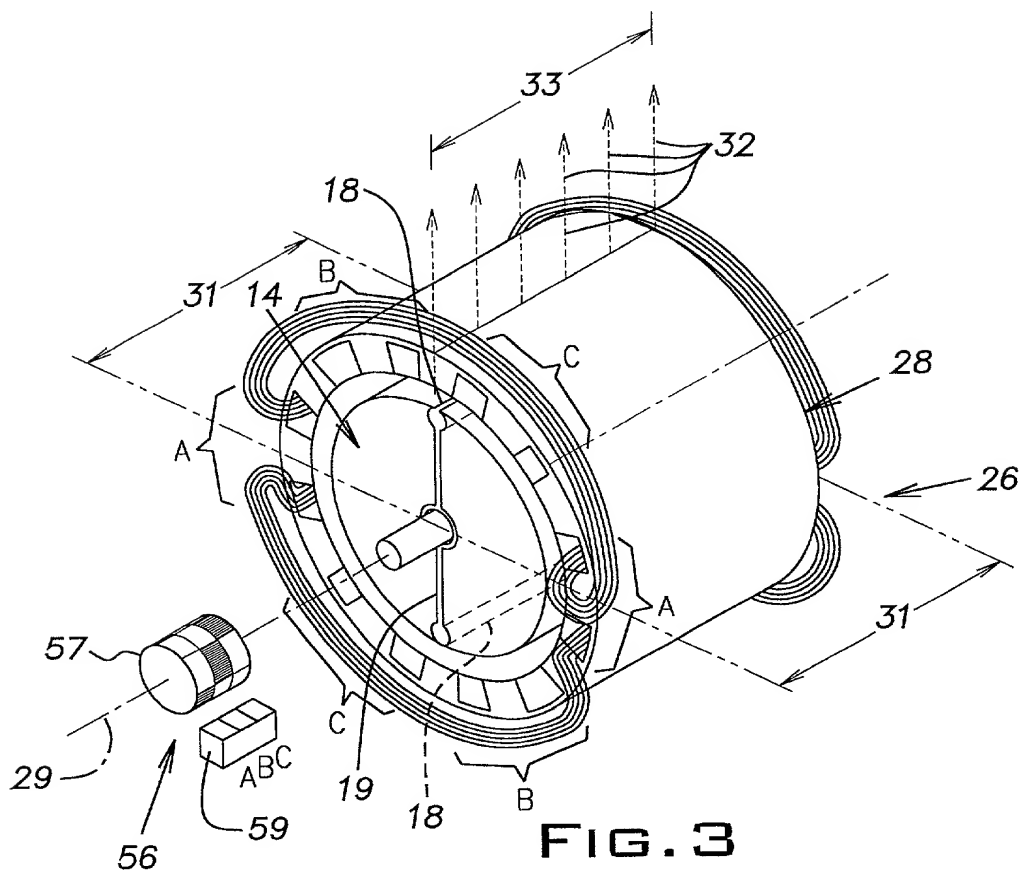
1                    CONTROLLED RELUCTANCE AC INDUCTION MOTOR

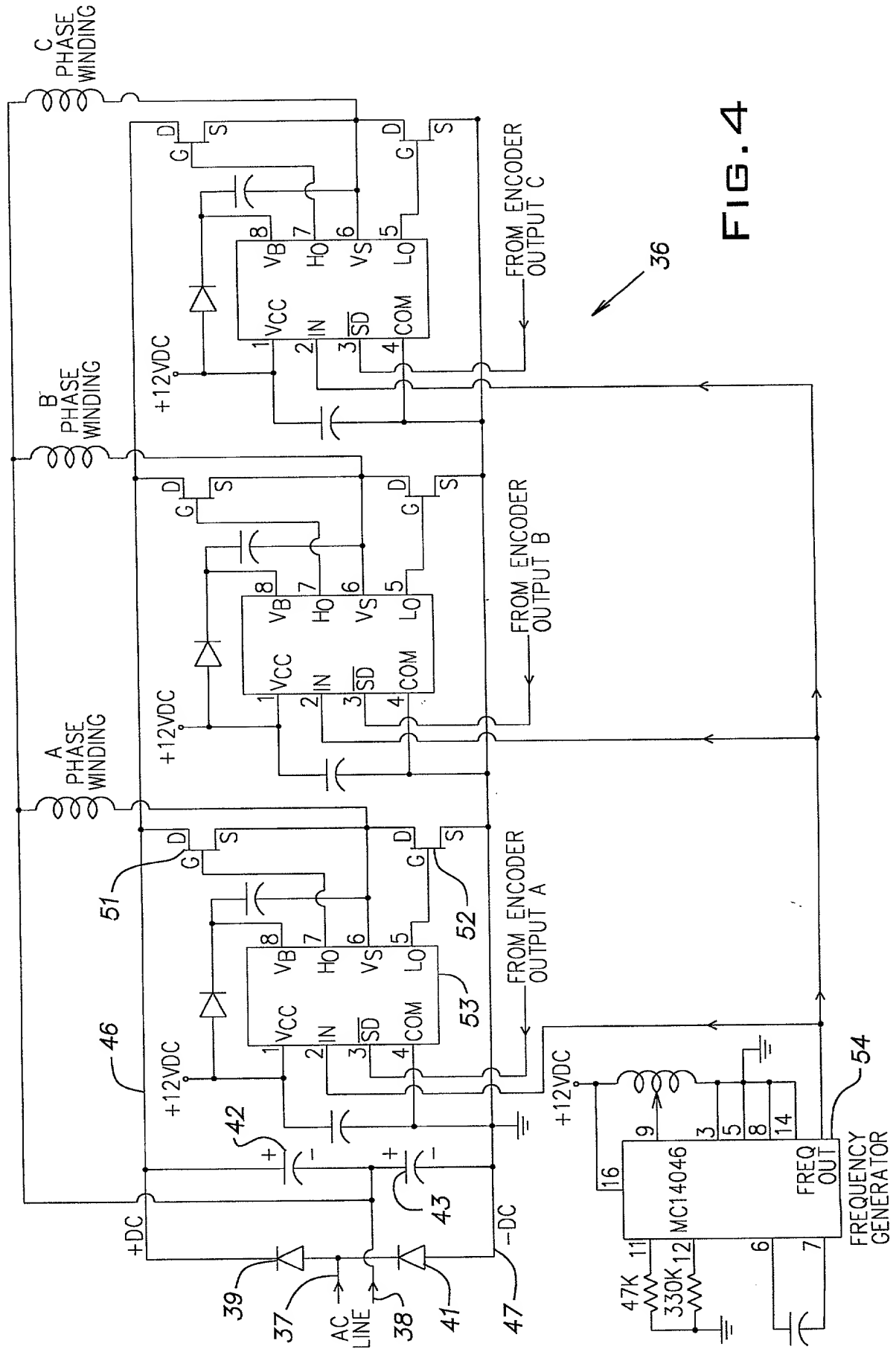
2                    ABSTRACT OF THE DISCLOSURE

3                    An electric motor operated by AC current, that includes  
4                    a stator and a rotor supported for rotation about an axis  
5                    relative to the stator. The stator is provided with field  
6                    windings angularly distributed about the rotor axis and  
7                    capable of producing a magnetic field vector in the space of  
8                    the rotor. Circuitry delivers AC current to the windings in  
9                    a manner that produces an AC magnetic field vector that  
10                   moves around the axis of the rotor. The rotor has a  
11                   construction, such as an axially extending conductive loop,  
12                   that changes its reluctance in the AC magnetic field  
13                   depending on its orientation to the AC magnetic field vector  
14                   whereby the rotor is caused to rotate in synchronization  
15                   with the movement of the AC magnetic field vector.

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INVERTER SQUARE WAVE

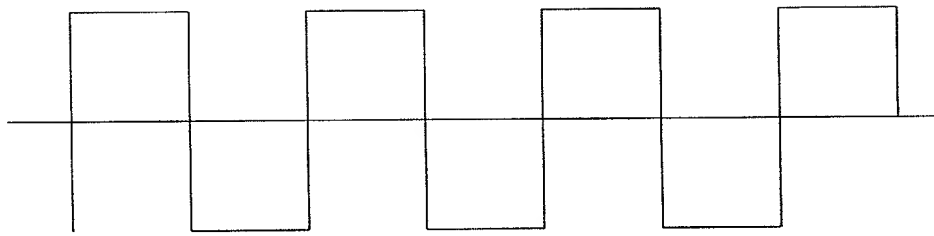


FIG. 6A

CYCLE WIDTH CONTROL OF POWER

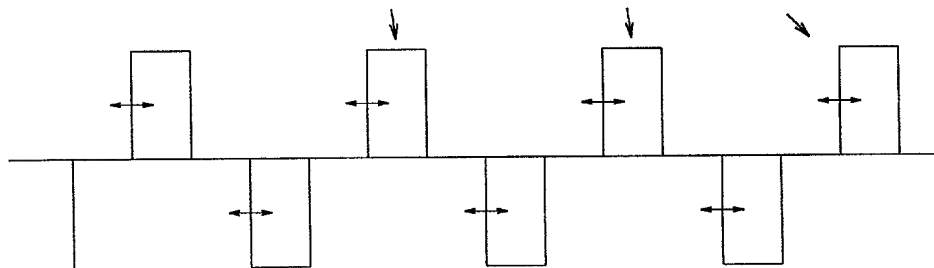
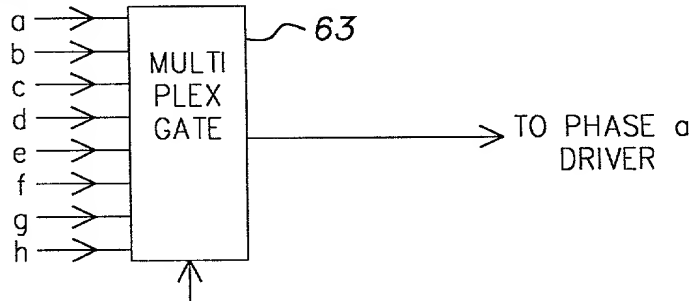


FIG. 6B

SHAFT SENSOR SIGNALS



SHAFT SENSOR SIGNALS

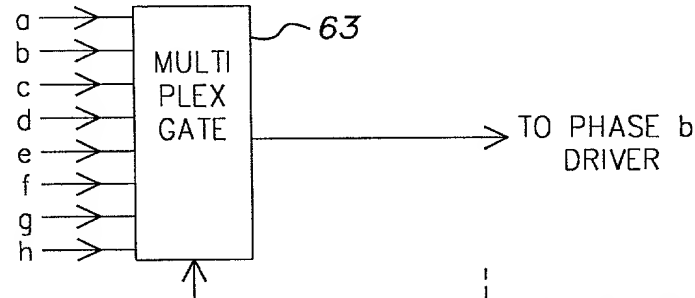
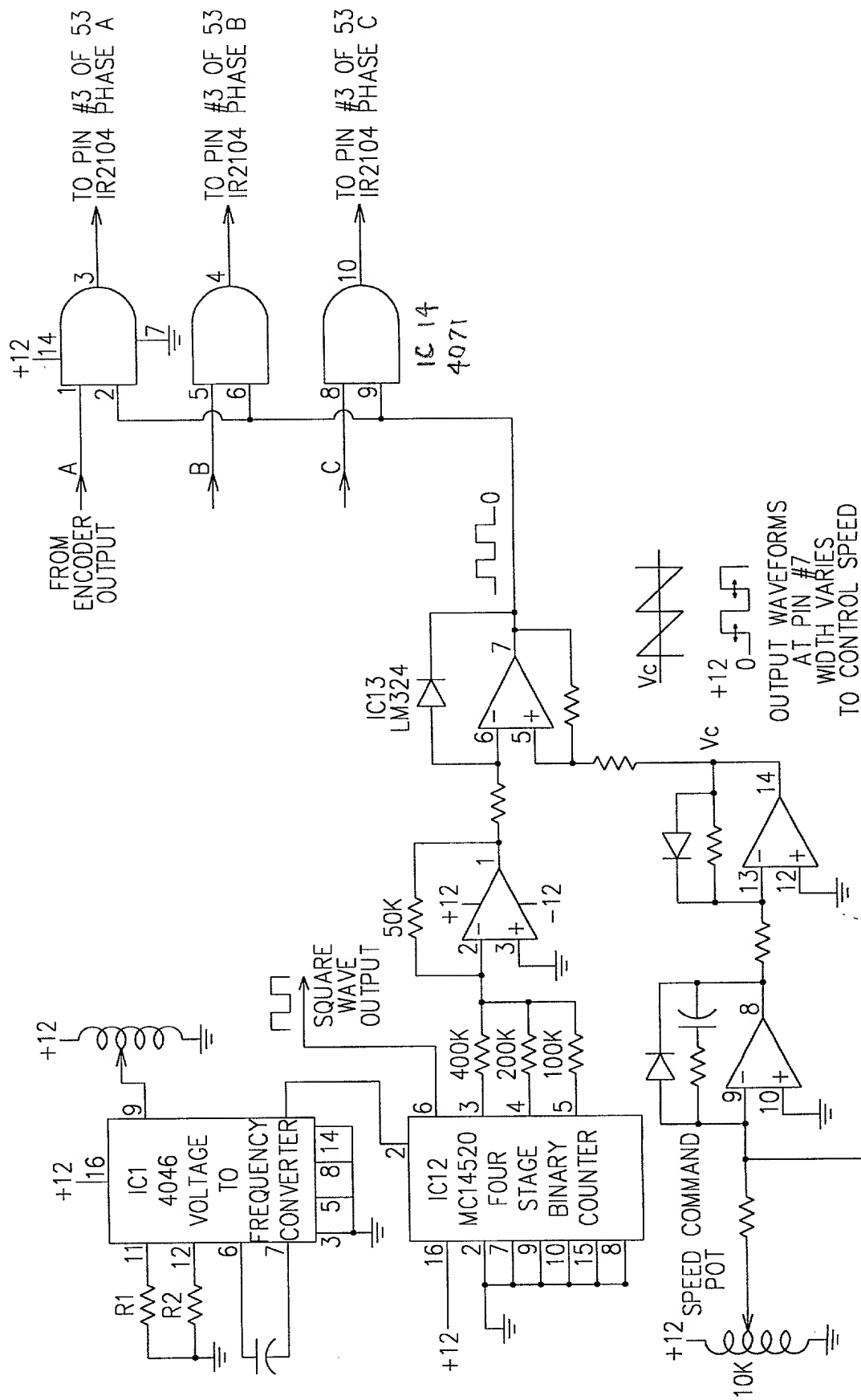


FIG. 9

AND SO ON FOR ALL EIGHT PHASES





SPEED CONTROL METHOD BY VARYING THE CYCLE WIDTH OF THE POWER FREQUENCY

FIG.7

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SAWTOOTH WAVEFORM AT PIN#1 IC13

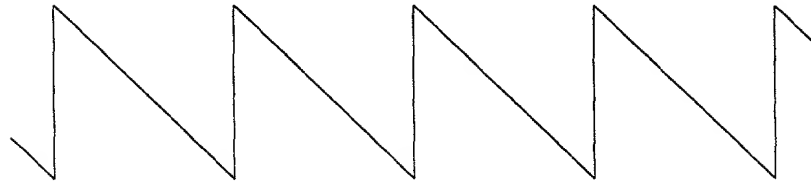


FIG.8A

SQUARE WAVE OUTPUT PIN#6 IC12

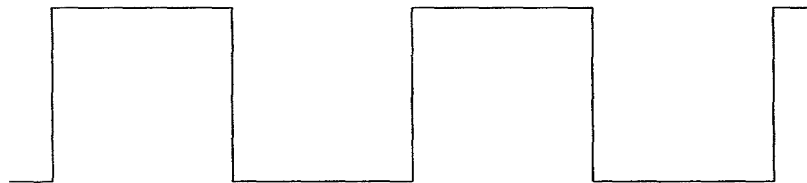
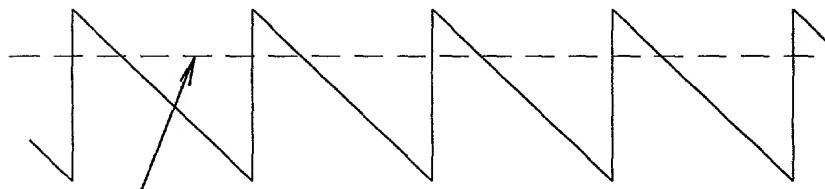
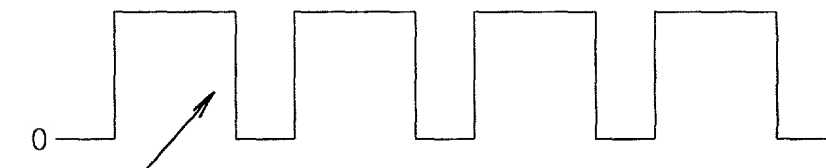


FIG.8B



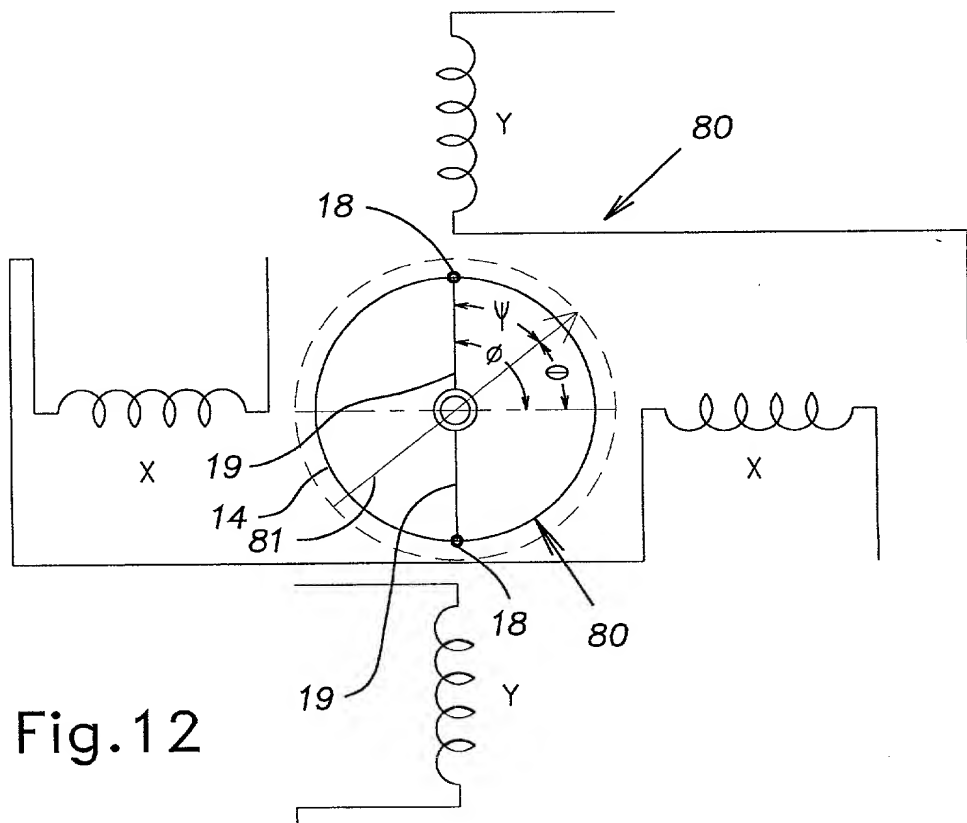
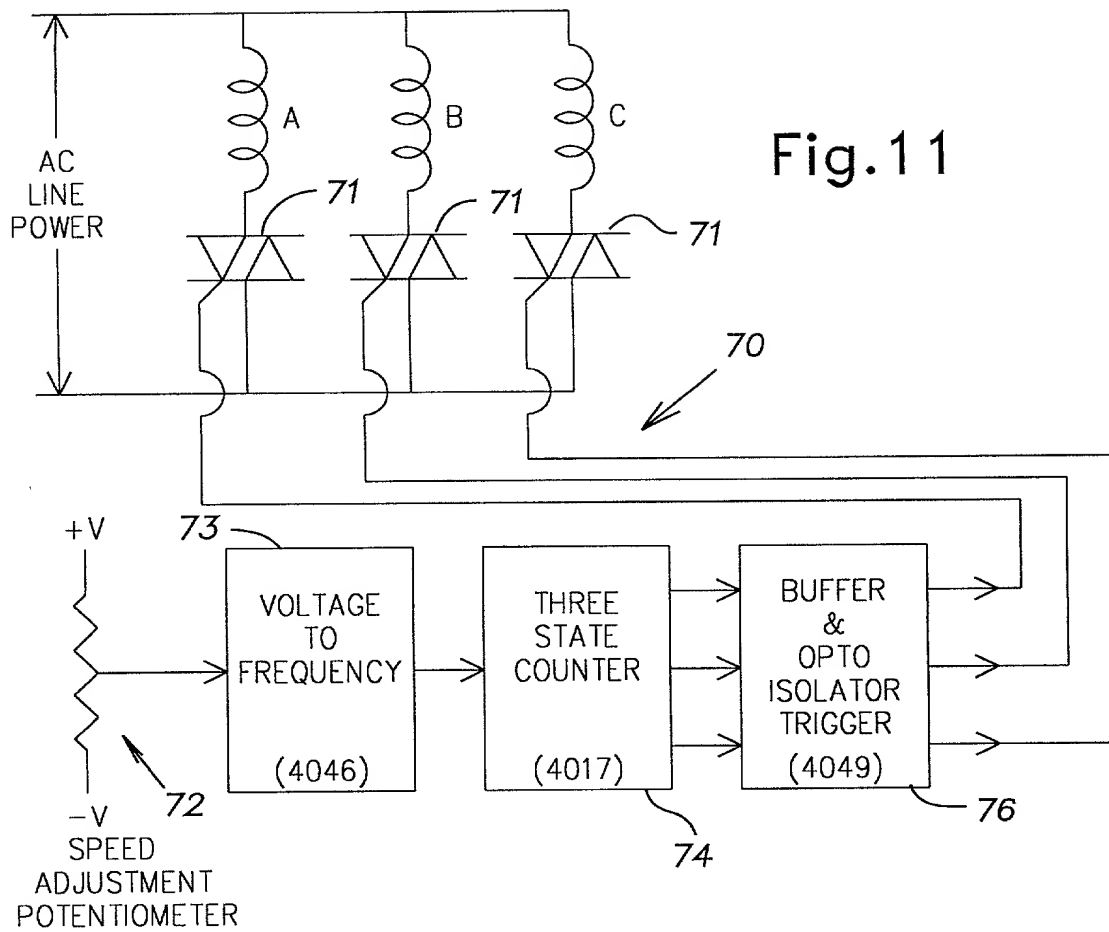
SPEED ERROR  
SIGNAL LEVEL

FIG.8C



OUTPUT AT  
PIN#7 IC13

FIG.8D





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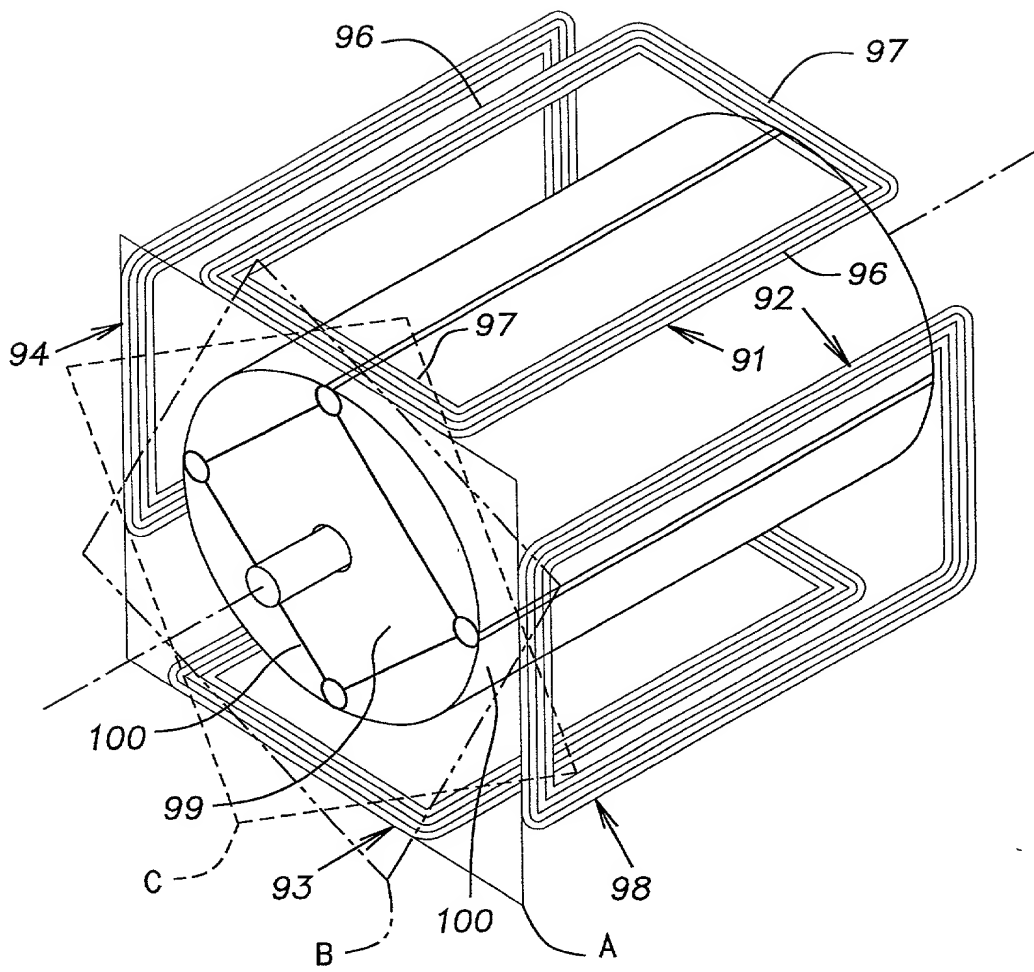


FIG. 14

**DECLARATION AND POWER OF ATTORNEY**  
(Sole Inventor)

I, Lambert Haner, hereby declare that I am a citizen of the United States of America and a resident of 1975 Wynwood Drive, Rocky River, Ohio 44116; that I have reviewed and understand the content of the attached specification, including the claims (Pearne & Gordon LLP Docket No. 28870), and I believe that I am the original, first, and sole inventor of the subject matter which is claimed therein and for which a patent is sought on the invention or discovery entitled

**CONTROLLED RELUCTANCE AC INDUCTION MOTOR**

and that I acknowledge my duty to disclose information of which I am aware which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby designate the following as my mailing address and telephone number:


Pearne & Gordon LLP  
526 Superior Avenue, East  
Suite 1200  
Cleveland, Ohio 44114-1484  
(216) 579-1700

and appoint each of the following as my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Charles B. Gordon, Reg. No. 16923  
Richard H. Dickinson, Jr., Reg. No. 18622  
Thomas P. Schiller, Reg. No. 20677  
David B. Deioma, Reg. No. 22841  
Joseph J. Corso, Reg. No. 25845  
Howard G. Shimola, Reg. No. 26232

Jeffrey J. Sopko, Reg. No. 27676  
John P. Murtaugh, Reg. No. 34226  
James M. Moore, Reg. No. 32923  
David E. Spaw, Reg. No. 34732  
Michael W. Garvey, Reg. No. 35878  
Aaron A. Fishman, Reg. No. 44682

I further declare that all statements made herein of my own knowledge are true and that all statements made herein on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.



Lambert Haner

Date SEPT. 3, 2000

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